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Title: Resolving the Position of a Fission Source in a 3He Well Counter Using List-Mode Analysis

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Resolving the Position of a Fission Source in a ^{3}He Well Counter Using List-Mode Analysis

Keepin Lightning Presentation

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NEN-1

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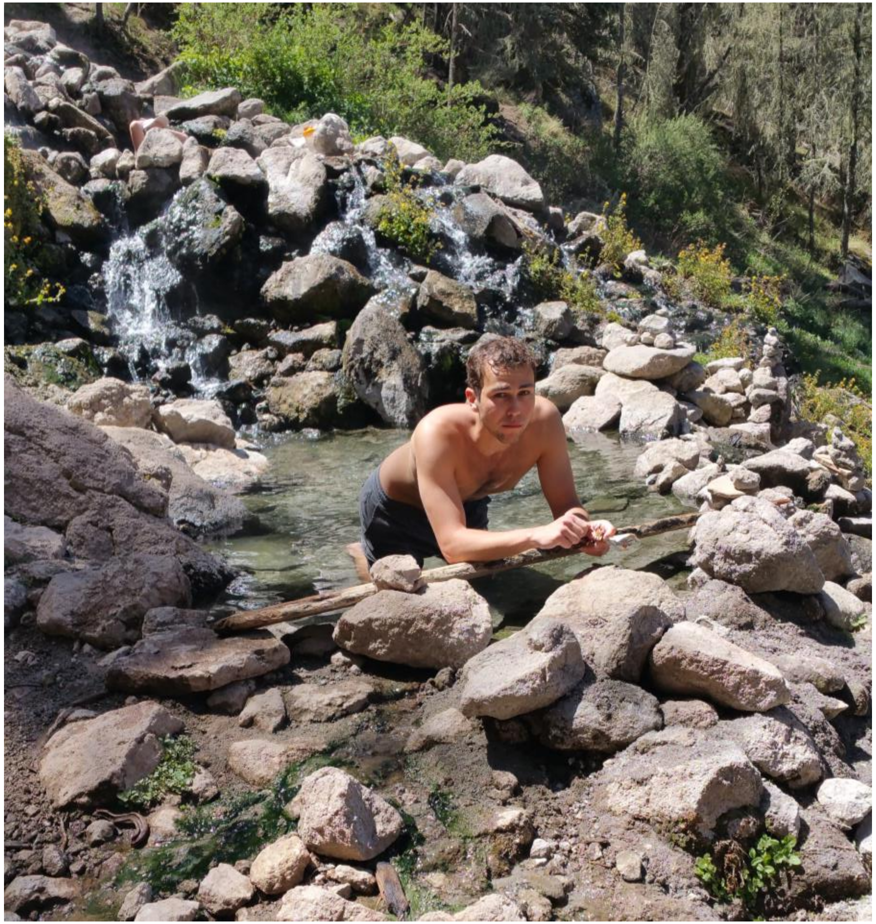
LA-UR-XXXXXX

Summer Fun: San Antonio Hot Springs



Nathan Giha
American, born 1997

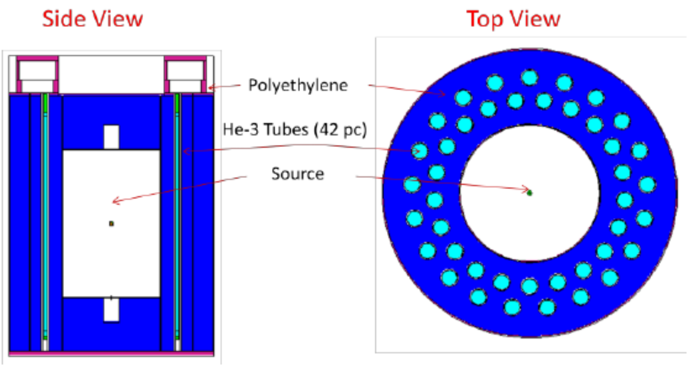
Bondin at the Springs
2018
Photograph

Courtesy the artist

Nathan Giha (NEN-1)

- Educational Background
  - University of Michigan
  - B.S.E. in Nuclear Engineering and Radiological Sciences, expected May 2019
- Division
  - NEN-1
  - Mentored by UMich alumnus Marc Ruch
- Research
  - Resolving the Position of a Fission Source in a ^{3}He Well Counter Using List-Mode Analysis

Overview and Motivation



E. C. Miller et al.

- **Well coincidence counters are:**
  - Widely used in safeguards to verify mass declarations of SNM by measuring fission neutrons
  - Normally used with a shift register, which sums all signals together
    - Designed to be insensitive to fission source position
    - Not being used to the instrument's full potential
    - List-mode analysis can yield more information
      - Detect attempted "spoofing" with multiple sources

JCC-51 AWCC
(canberra.com)

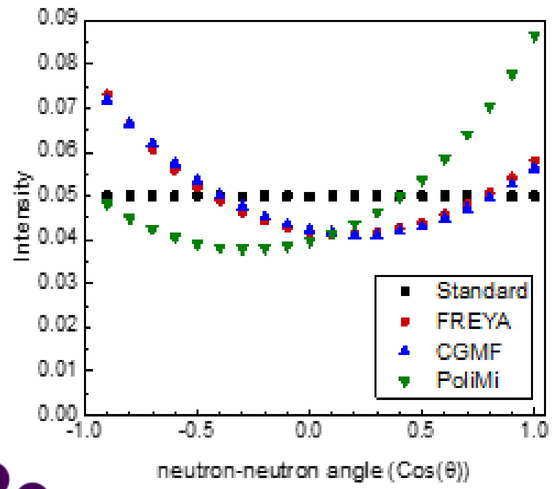
- **Goal: Locate a point fission source within a well coincidence counter using list-mode analysis**

Principles of the Technique

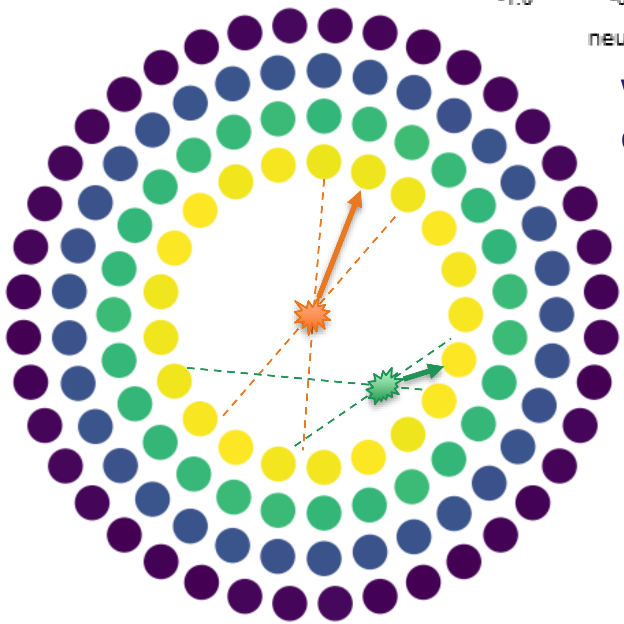
Concept:

- If ^{3}He tubes are read out separately, one can determine the position of a fission neutron source due to:
  - Anisotropy of neutron emission
  - Geometric efficiency of individual tubes

- The angle between detected coincident neutrons will be different, depending on the distance from the source to the well's center



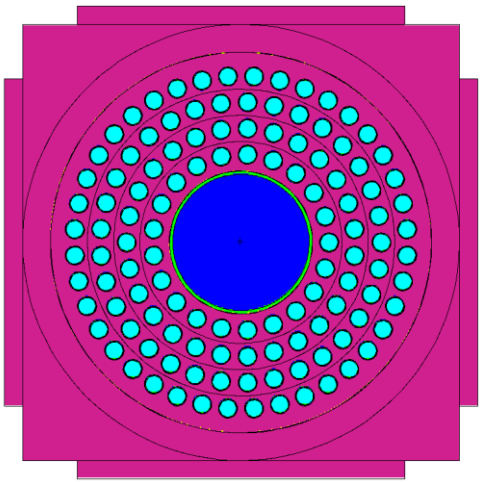
Weinmann-Smith et al.

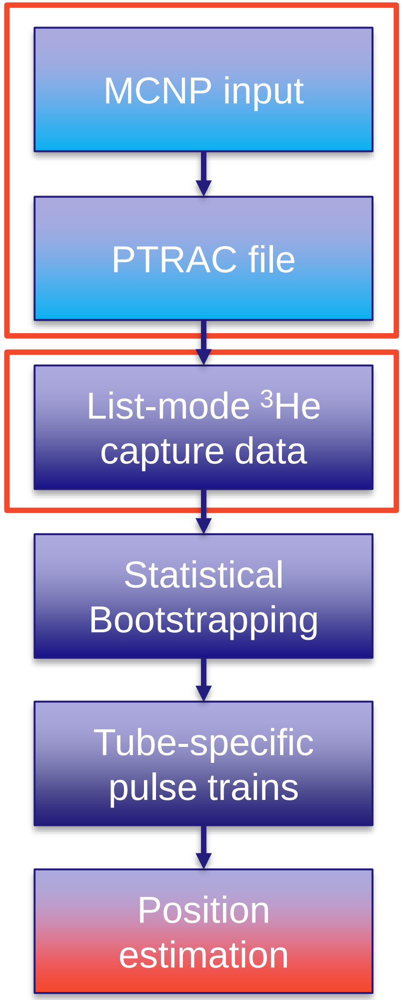


Method

Simulation:

- Epithermal neutron multiplicity counter (ENMC) in MCNP [2]
- FREYA fission model [3] – anisotropy of neutron emission must be modeled
- PTRAC card – collect event-by-event tube-specific data





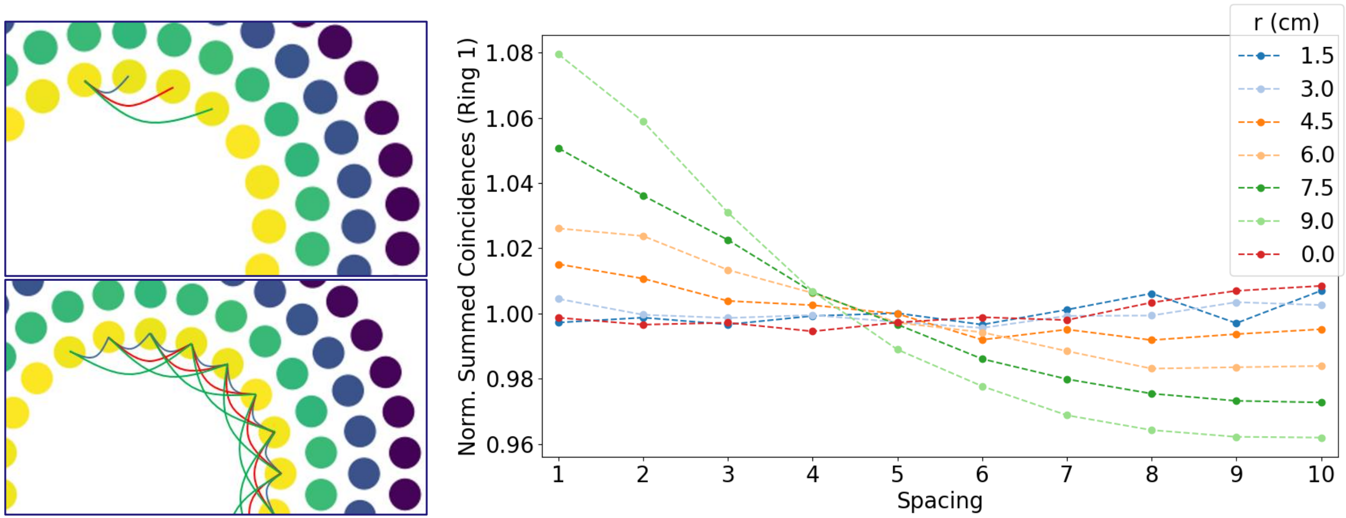
Pre-Processing:

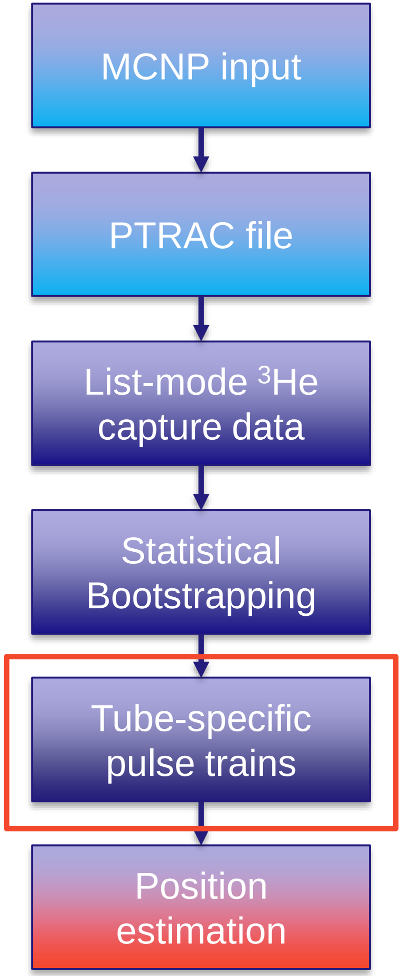
- Truncate PTRAC file into list-mode file of neutron captures on ^{3}He

Method

Processing:

- Perform shift register analysis on pairs of ^{3}He tubes
  - Vary spacing between selected tubes and calculate coincidences
  - For each spacing, sum all coincidences from tube pairs together

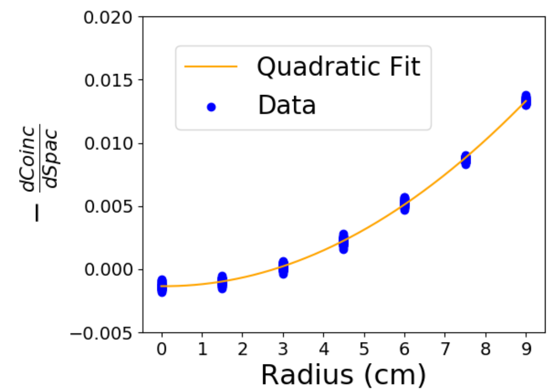


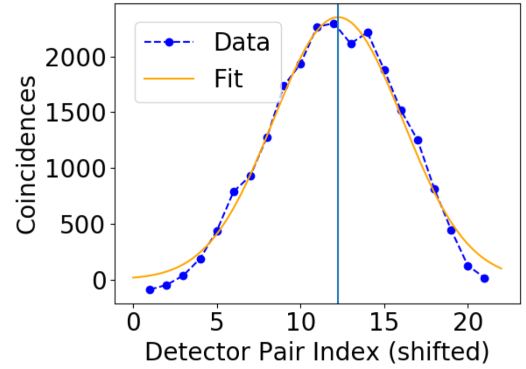


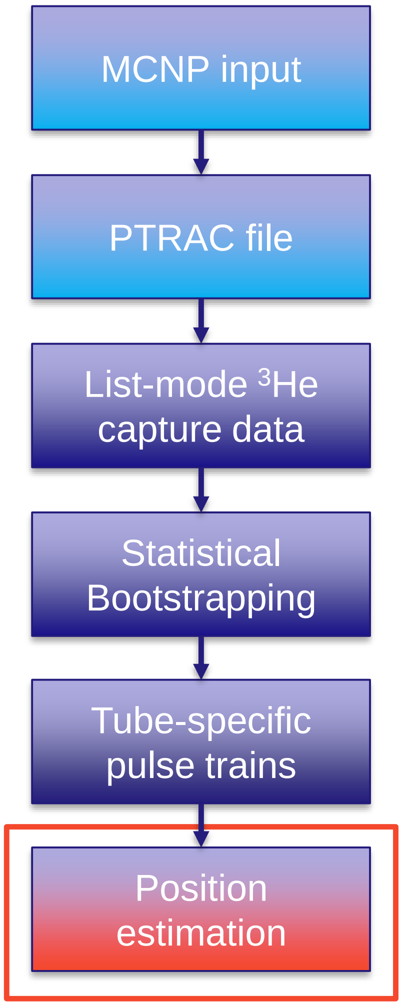
Method

Post-Processing:

- Resolving radius:
  - Generate calibration curve
    - Simulate a range of positions that span the radius of the well
    - Perform linear fit on coincidence-spacing plot for each position
    - Plot derivative of fit vs. radius, fit with quadratic, and invert



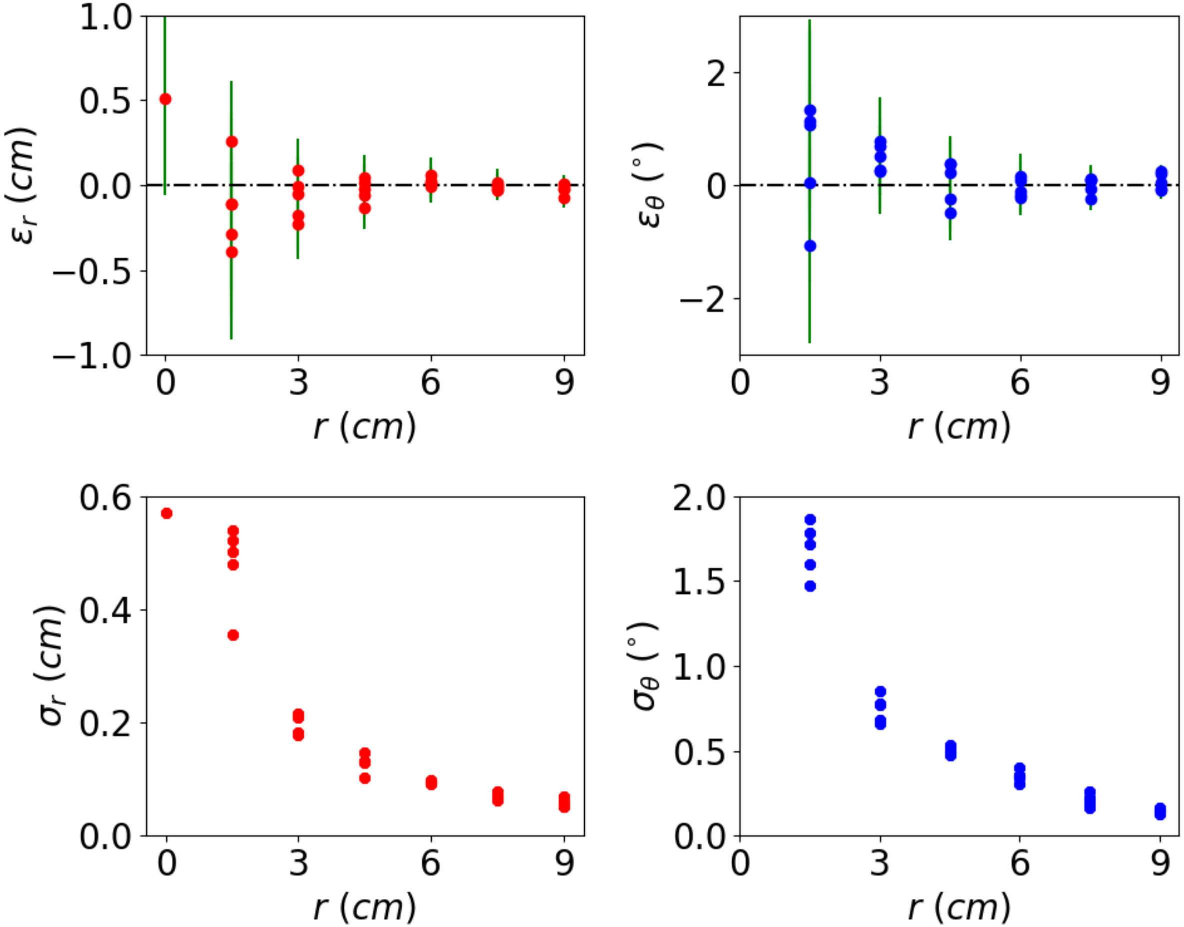




- Resolving polar angle:
  - Plot coincidences vs. adjacent detector pairs
  - Fit Gaussian
  - Convert mean of Gaussian to polar angle

Results and Error Analysis

- Performed statistical bootstrapping [4] to generate 50 smaller list-mode files for each source position
- Error is largest at the center of the well where:
  - Systematic error from the calibrations are $\varepsilon_r = 0.5$ cm and $\varepsilon_\theta = 1.3°$
  - Random errors are $\sigma(\varepsilon_r) = 0.5$ cm and $\sigma(\varepsilon_\theta) = 1.8°$



Future Work

- **Generate additional statistics through longer simulations and more extensive bootstrapping**
- **Perform rigorous analysis on multiple neutron source scenarios**
- **Investigate distributed fission sources**
  - Ability to accurately locate
  - Ability to distinguish from point source
- **Utilize coincidence data from outside rings**
- **Explore other fitting functions for coincidence vs. spacing data**
- **Validate simulation work with measurements**

References

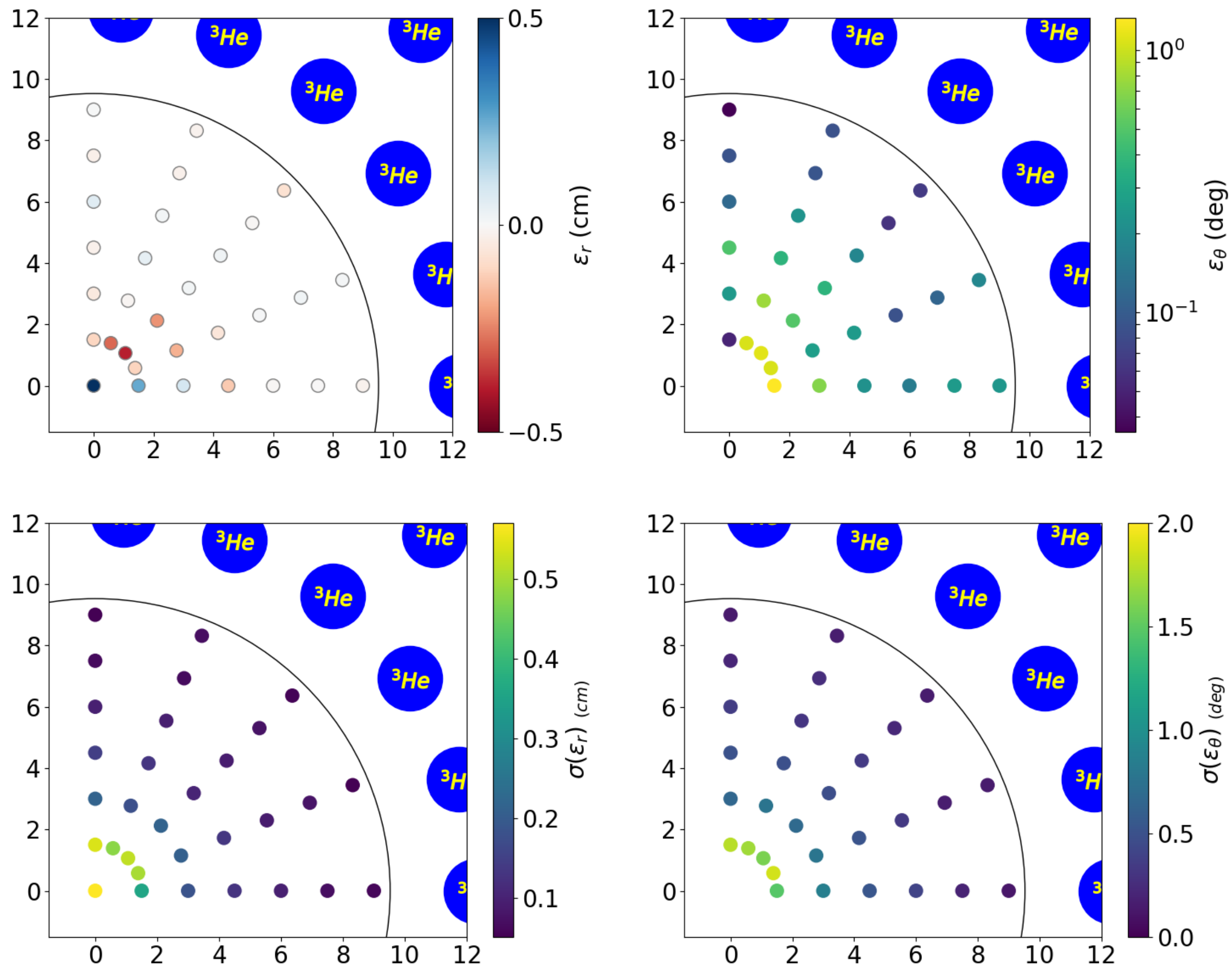
[1] Reilly, D. et al. "Fast and Epithermal Neutron Multiplicity Counter," LA-UR-07-1602.

[2] Weinmann-Smith, Robert et al. "A comparison of Monte Carlo fission models for safeguards neutron coincidence counters." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 903. 10.1016/j.nima.2018.06.055.

[3] Efron, B. "Bootstrap Methods: Another Look at the Jackknife." Ann. Statist. 7 (1979), no. 1, 1--26. doi:10.1214/aos/1176344552.

BACKUP SLIDES

Visualization of Error



Processing Scripts

- **VaryPosition.py:** Generates MCNP input files for a range of source positions specified in a config file
- **Ptrac_auto.py:** Takes PTRAC (.p) file as input and outputs truncated list-mode data (.po) in the following format for neutron captures in ^{3}He:

  NPS
  Cell
  Time
  NPS
  Cell
  Time

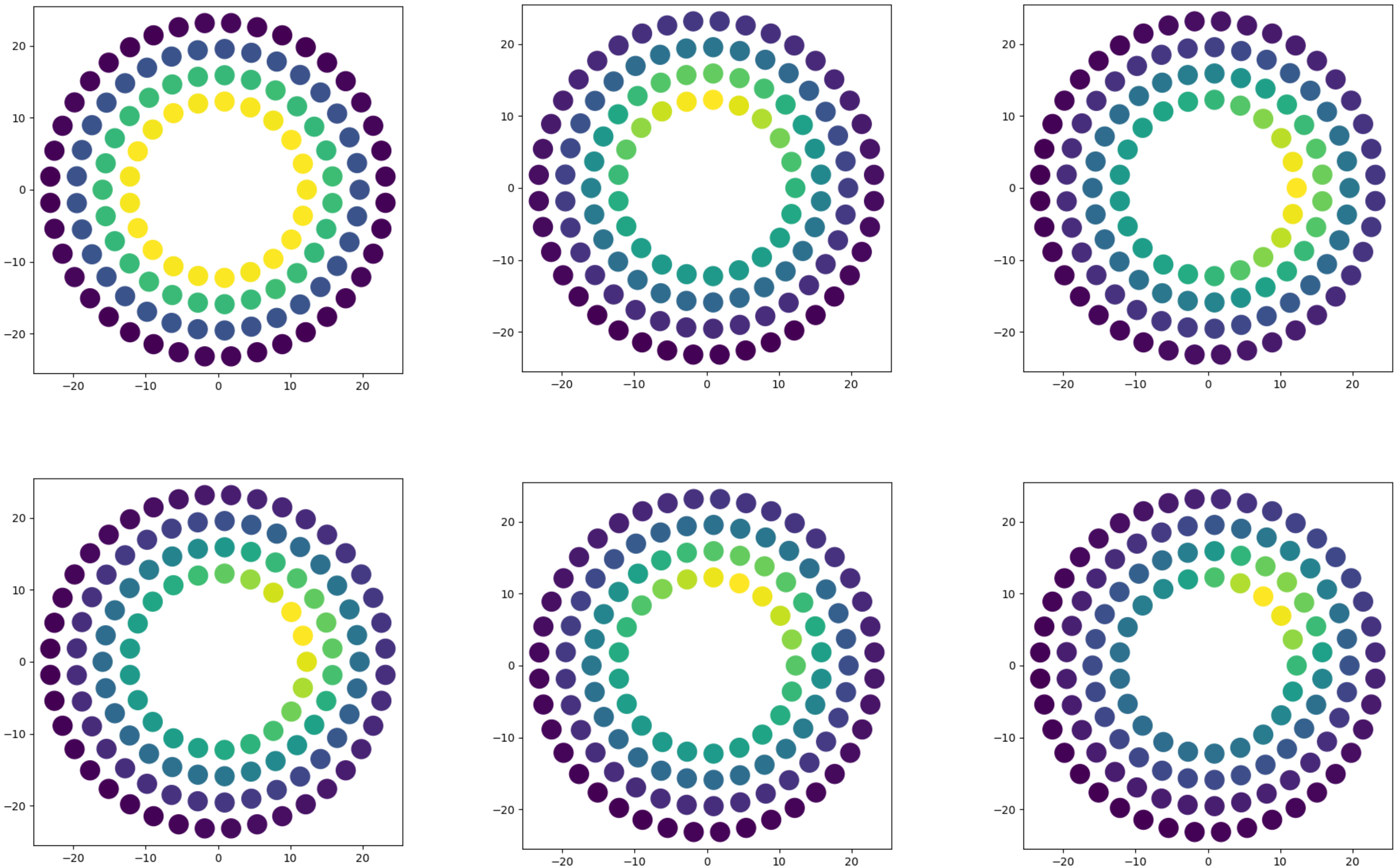
- **ShoeLace.py:** Takes list-mode data (.po) and generates N statistically bootstrapped files (.pob) with M histories each
- **PulseTrain.py:** Reads list-mode data (.po & .pob) and generates tube-specific pulse trains, performs shift register analysis, and generates figures and relevant data for post-processing (.pldat)
- **AutoAnalyze.bat:** Performs all of the above tasks for a range of source positions, specified in a computer generated config file

Processing Scripts Cont.

- **ReadGraphs.py:** Takes processed data (.pldat) and performs position calibration and/or estimation, as well as error analysis and figure generation

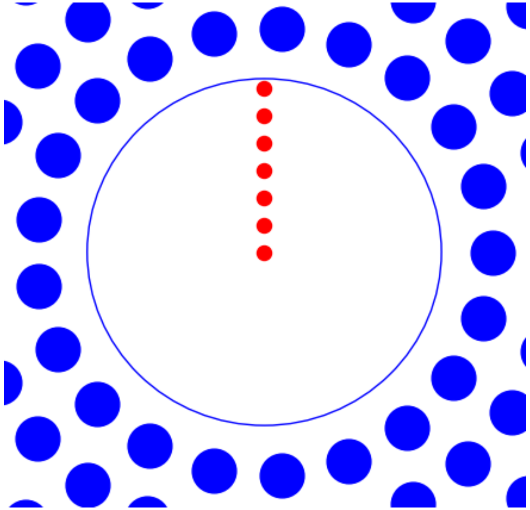
Notes on Simulations and Statistical Bootstrapping

- 31 Positions
- ~2e7 fissions per position – yields a 20GB PTRAC file
- 50 statistically bootstrapped list-mode files per position
  - 6e6 fissions each
  - Neutron yield approximately corresponds to a 10 minute measurement of 100g of reactor-grade plutonium [PANDA manual]


20
10
0
−10
−20
−20
−10
0
10
20

Fitting

- **Calibration positions:**



- **Calibration curve inversion:**

$$-\delta = ar^2 + br + c$$

$$r = \frac{-b + \sqrt{b^2 - 4a(c+\delta)}}{2a}$$